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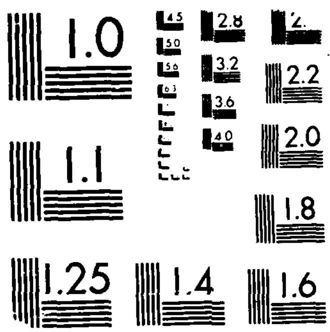

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TECHNICAL REPORT EL-87-9

NEW YORK WATER SUPPLY INFRASTRUCTURE STUDY

VOLUME IV: STATEN ISLAND

by

Thomas M. Walski, Roy Wade, Wayne W. Sharp

Environmental Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

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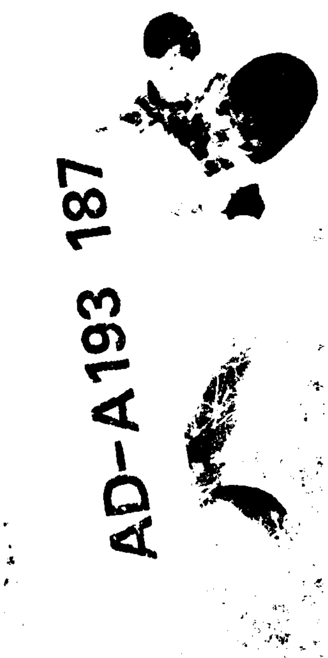

April 1988

Final Report

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19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

This report describes an evaluation of water main breaks in the Staten Island, New York, water distribution system. The report describes a statistical evaluation of historical pipe breaks and identifies patterns and trends in the data, including such things as the increase in circumferential pipe breaks during winter months and an increase in longitudinal breaks (probably due to surges) during summer months.

The actual break rates (in breaks per year per mile) were calculated for water mains with a history of breaks. This rate was compared with a critical break rate to determine which water mains should be replaced. The critical break rate was based on an economic evaluation of costs of replacement versus pipe repair and lost water from the existing mains. A list of recommended replacement projects and their costs is presented.

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PREFACE

This report describes a study conducted by the US Army Engineer Waterways Experiment Station (WES) for the US Army Engineer District (USAED), New York, under Inter-Army Order No. NYD 86-0015. The USAED, New York, was requested to perform this work by the State of New York in accordance with authorization in Section 214 of Public Law 89-298, and later under Section 22 of Public Law 93-251.

The study was conducted at WES by Dr. Thomas M. Walski and Mr. Wayne W. Sharp of the Water Resources Engineering Group (WREG) of the Environmental Engineering Division (EED), Environmental Laboratory (EL), WES, and Mr. Roy Wade of the Water Supply and Waste Treatment Group (WSWTG), EED. They were assisted by Mr. Anthony Lewis of WSWTG.

The work was monitored by Mr. David Schlessinger of the Planning Division of the USAED, New York, under the supervision of Mr. Tom Pfeifer.

This is the fourth volume of a series on the New York City water supply infrastructure. The first two volumes reported on the boroughs of Manhattan and Brooklyn, respectively; the third addressed the Bronx and Queens. A summary report for the City will conclude the series.

The pipe break data files were prepared by Betz, Converse and Murdoch, Inc. (BCM), under previous contracts with the USAED, New York. Mr. Ron DeRosa of BCM provided these files, plus other assistance to this study. BCM prepared the Manhattan and Brooklyn reports for the USAED, New York. The Bronx and Queens report was prepared by WES.

The point of contact with the Department of Environmental Conservation of the State of New York was Mr. Howard Pike. The point of contact with the New York City Department of Environmental Protection was Mr. Edward C. Scheader, Deputy Director of the Bureau of Water Supply. Additional support was provided by Mr. Martin Englehardt, Chief of Planning and Programs; Mr. Richard Siegel, Chief of Systems Operations; and Mr. Richard Gainer, Chief of Field Operations. Mr. Doug Greeley of the Field Operations Division prepared most of the data provided by the Bureau.

Technical review of this report was provided by Mr. M. J. Cullinane of the WSWTG and Dr. James W. Male of the Civil Engineering Department, University of Massachusetts, under the Intergovernmental Personnel Act. The report

was edited by Ms. Jessica S. Ruff of the WES Information Technology Laboratory.

The Acting Chief of WREG was Mr. F. Douglas Shields, Jr.; Chief of the WSWTG was Mr. Norman R. Francingues. The study was conducted under the general supervision of Dr. Raymond L. Montgomery, Chief of EED; Dr. John W. Keeley, Acting Chief, EL; and Dr. John Harrison, Chief, EL.

Commander and Director of WES was COL Dwayne G. Lee, CE. Technical Director was Dr. Robert W. Whalin.

This report should be cited as follows:

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CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres
pounds (force) per square inch	6.894757	kilopascals

NEW YORK WATER SUPPLY INFRASTRUCTURE STUDY

STATEN ISLAND

PART I: INTRODUCTION

Background

1. Deterioration of water systems can manifest itself in many ways, including increased expenditures for water main break repair and damages, excessive loss of water, decreased hydraulic carrying capacity, more frequent and severe water outages, and increased risk of system contamination.

2. While all system components deteriorate to some extent with time, most of the problems can usually be traced to a fraction of the system. Identification of those components that have experienced problems and projection of trends can be used to identify those system components which, when replaced, will result in a savings in overall replacement and repair costs.

3. Because of a concern over the water supply infrastructure in New York City, the Department of Environmental Conservation of the State of New York asked the US Army Engineer District (USAED), New York, to analyze the condition of the water supply infrastructure in New York City. The City has an active leak detection program and the distribution system in general has adequate hydraulic carrying capacity. Therefore, this series of studies focused on the problems of water main breaks.

4. Studies of the Manhattan and Brooklyn distribution systems were conducted by Betz, Converse and Murdoch, Inc. (BCM) (USAED, New York 1980, 1984), and a study of The Bronx and Queens was conducted by the US Army Engineer Waterways Experiment Station (Walski and Wade 1987). This volume is the fourth in the series and covers the borough of Staten Island. The series will be concluded with a summary report for the City.

Purpose

5. The purpose of this study was primarily to assess water distribution infrastructure needs. Since it was decided that the most pressing problem was

water main breaks, this study concentrated on identification of water mains requiring replacement.

6. With this report, the Bureau of Water Supply can better identify priority water main replacement projects. The Bureau of Water Supply also should have a better appreciation for the causes of breaks and the costs involved with repair and replacement on a borough-wide basis.

Overview

7. The study was divided into two portions: (a) statistical analysis and (b) identification of replacement projects.

8. Part II consists of the statistical analysis of water main breaks. Break rates (in breaks per year per mile) are calculated borough-wide for different sizes of pipe, types of break, time period laid, season, and age of pipe. The results give some insights into the types of breaks in Staten Island.

9. In Part III, the critical break rate for pipes is determined as a function of diameter. Then, the actual break rates for pipes with past breaks are calculated for potential replacement projects. The actual break rates are compared with the critical break rate to determine which water mains have rates greater than the critical rate and should be replaced. Budget estimates for these replacement projects are then prepared.

10. This volume of the New York Water Supply Infrastructure Study differs from the previous three in that it does not contain a great deal of background material on causes of breaks or derivation of equations. There are excellent discussions of the causes of water main failures in the Manhattan and Brooklyn reports (USAED, New York 1980, 1984). The derivation of replacement rules for water mains is developed in the Bronx and Queens report (Walski and Wade 1987). This volume is an engineering report on Staten Island, with references to information in the previous volumes.

PART II: STATISTICAL ANALYSIS OF WATER MAIN BREAK DATA

11. Statistical analysis of historical data on water main breaks in Staten Island is helpful in identifying patterns and trends in pipe breaks and gaining insights into possible remedial measures. The following sections describe the available data and discuss patterns and trends in pipe breaks in Staten Island, which in some cases are compared with results of similar analyses in other boroughs.

Data Sources

12. The results presented in this section were developed from several computerized data bases. The two most important were the New York City fixed assets file and a data base containing data on most pipe breaks in Staten Island between 1941 and 1980.

13. The fixed assets file was prepared by a contractor for the City of New York and contains a considerable amount of information about the infrastructure in the City. First, records concerning water distribution mains were extracted from that file on a borough-by-borough basis. Accounting information was then removed from each record, and an inventory file was prepared. For each pipe segment in the distribution system, the following information was available:

- a. Face street and two cross street names.
- b. Face street and two cross street codes.
- c. Pipe diameter.
- d. Year pipe was laid.
- e. Pipe material.
- f. Pressure zone.

The "face street" is the street under which the pipe is laid while the "cross streets" are streets at each end of a block. For example, for a water main laid in Oak Street between Washington and Jefferson Streets, Oak is the face street while Washington and Jefferson are the cross streets.

14. Data on pipe breaks for the years 1941 through 1980 were available in the pipe break file developed for an earlier part of the New York City study. This file was prepared for the USAED, New York, by a contractor (Betz,

Converse and Murdoch, Inc. 1981). For each break recorded, the following information was available:

a. Date of break.

b. One or two street names (sometimes with an address).

c. Pipe diameter.

d. Year pipe was laid.

e. Code for type of break.

f. Code for cause of break.

g. Pipe thickness.

h. Code for corrosion.

i. Code for contact with structures.

j. Code for damages.

k. A census block and tract.

Unlike the other boroughs, there was a serious problem with the Staten Island data in that a considerable number of the break reports were missing for the periods 1955-57, 1967-68, and 1974-75, and no break reports were available for 1947 and 1949-50. This lack of data was accounted for in calculating water main break rates. However, the missing data made it impossible to perform some of the analyses on the effects of aging of pipe on break rate, as was done for The Bronx and Queens.

15. In spite of the problems with the data files, enough information was available to perform the limited statistical analyses reported in this part of the report and to calculate the pipe break rates given in Part III.

16. Another source of data was the US Census Bureau's GBF-DIME (Geographic Base File-Dual Independent Map Encoding) file, which contains information on the streets that border each census block. Although it does not contain any data on pipes, it was helpful in resolving discrepancies between the inventory and break files.

17. The New York City Bureau of Water Supply also provided data on the number of miles of water mains in the borough and number of breaks as a function of time since 1933. This information was helpful in checking on completeness of inventory and break files and performing a limited analysis of pipe break trends.

Inventory of Water Mains

18. A summary of the inventory of the Staten Island distribution system, based on the New York City fixed assets file, is presented in Table 1. It gives the length of pipe laid by pentad and diameter.

19. The Staten Island water distribution system is composed primarily of 8-* and 12-in.-diam pipe. Pipes less than 8 in. in diameter account for only 4 percent of the system, while pipes larger than 12 in. account for 11 percent of the system. As was the case for the other boroughs, 6-in. water mains are gradually being phased out in favor of pipes with greater beam strength and hydraulic carrying capacity. In the early years, 6-in. pipe made up a reasonably large portion of the system but has been laid only sparingly in recent years.

20. Table 1 also shows that most of the water system was laid between 1920 and 1939, with those years accounting for 38 percent of the system. In recent years, water mains have been laid at a rate of roughly 7 miles per year, and the 8- and 12-in. diameters continue to be the most popular.

21. While the inventory file was supposed to contain data on pipe materials, such data proved to be virtually meaningless on close examination.

22. Table 1 shows that there are 787 miles of water main in place in Staten Island. This is roughly 7 percent less than the 843 miles reported by the Bureau of Water Supply as of 1985. This is apparently due to the fact that: (a) small pipes and those with odd diameters are not included in the fixed assets file and (b) some pipe segments appear to be missing from the fixed assets file.

23. Water main construction practices in Staten Island (summarized in Table 2) are similar to those in other boroughs.

Water Main Break Analysis

24. In Staten Island, data were available for 668 water main breaks. As was the case for the other boroughs, some data entries in each record were

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 4.

Table 1

Inventory of Staten Island Water Mains

Installation Date	6	8	12	16	20	24	30	36	48	54	60	72	Total Feet	Total Miles	Total Percentage
	Length, ft, by Diameter (in.) Categories														
Pre-1900	33726	136355	68666	5485	10316	3730	2000	500	4805	0	1790	5575	273951	51.88	6.6
1900-1904	130	120	140	270	900	0	0	0	0	0	0	0	1760	0.33	0.0
1905-1909	530	810	1235	6390	15840	0	60	0	0	0	0	0	24865	4.71	0.6
1910-1914	13965	119526	106502	1000	24851	37780	1370	725	9660	0	2760	975	309214	58.56	7.4
1915-1919	9980	42155	15095	0	1775	1710	0	0	1110	0	150	415	72490	13.73	1.7
1920-1924	10461	170472	56305	17895	12185	2785	30	0	1180	0	1515	360	273188	51.74	6.6
1925-1929	16635	328574	123878	30377	17285	11935	1525	0	8870	0	1405	1520	542004	102.65	13.0
1930-1934	12041	224222	68196	10705	7720	2630	230	0	1620	0	1	0	327365	62.00	7.9
1935-1939	19935	289658	100792	20931	9585	3285	20	0	3470	0	380	2995	451041	85.42	10.9
1940-1944	18720	161902	52912	22686	12485	2760	0	540	4725	0	5260	1171	278161	51.68	6.7
1945-1949	13910	159917	59476	8480	6880	3215	70	390	2780	0	570	1170	256868	48.65	6.2
1950-1954	2220	154401	32340	1850	4470	1100	0	0	0	0	0	0	202381	38.33	4.9
1955-1959	3015	190343	25210	5130	6475	0	0	0	1100	0	460	0	231733	43.89	5.6
1960-1964	1865	172566	40555	3530	4860	4620	0	0	450	0	0	0	228446	43.27	5.5
1965-1969	1600	160431	44540	1740	2060	0	0	0	0	0	0	0	210471	39.86	5.1
1970-1974	2170	111687	59326	2050	1790	3300	0	0	0	0	0	0	180273	34.14	4.3
1975-1979	330	79910	35222	110	0	0	0	0	0	0	0	0	115572	21.89	2.8
1980-1985	0	54905	50508	0	16420	0	70	5085	635	1100	0	0	174804	22.11	4.2
Total feet	163443	2587977	942998	138639	155998	78850	5375	11240	40405	1100	14381	14181	4154587		
Miles	30.96	490.15	178.60	26.26	29.55	14.93	1.02	2.13	7.65	0.21	2.72	2.69		786.85	
Percentage	(3.9)	(62.3)	(22.7)	(3.3)	(3.8)	(1.9)	(0.1)	(0.3)	(1.0)	(0.0)	(0.3)	(0.3)			(100)
Total*	198964	2940465	1031773	168505	--	69220	2962	24543	54772	1713	22	10230	4508159		

* Totals represent net placement to date and are generated from data available subsequent to preparation of the rest of Table 1 and the rest of this report.

Table 2

Water Main Construction Practices in New York City

Period of Construction*	Type of Pipe	Type of Joint	Strength, 1,000 psi Bursting Tensile	Strength, 1,000 psi Ring Modulus
Pre-1870	Horizontally cast iron pipe	Bell and spigot, with lead caulking	Unknown	
1870-1929	Vertically (pit) cast iron pipe	Bell and spigot, with lead caulking	11	31
1930-1965	Centrifugally cast iron pipe, with interior cement lining	Bell and spigot, with lead caulking	18	40
1970-1974	Ductile iron pipe, with interior cement lining	Bell and spigot, with lead caulking	42	72
1975-present	Ductile iron pipe, with interior cement lining	Push-on joint, with rubber O-ring	42	72

Source: US Army Engineer District, New York 1980.
* Staten Island did not become part of New York City until 1898.

missing, which limited the types of statistical analyses. However, some analyses were performed, as described in the following paragraphs.

Types of breaks

25. The type of break (e.g., circumferential, longitudinal) was indicated on virtually every water main break record. These data are presented in Table 3 and Figure 1.

26. While circumferential breaks were common for 6-in. water mains, longitudinal breaks are more common for larger diameters. This is in contrast with the other boroughs in which 8-in. pipes also had more circumferential breaks than 6-in. This may indicate that external loadings are less severe in Staten Island. Conversely, internal loadings on pipes may be greater in Staten Island than the other boroughs, resulting in a higher rate of longitudinal breaks due to internal forces. This is supported by the fact that considerably more pumping occurs in Staten Island, and a certain amount of waterhammer is associated with pumping. In addition, sometimes tanks are taken off line during the summer months. This limits the distribution system's ability to withstand waterhammer since tanks tend to dampen out surges.

Effect of diameter on break rates

27. As was the case for the other boroughs, 6-in. pipes experienced the highest break rates in Staten Island. This is shown in Figure 2 and is consistent with similar observations in other boroughs. This supports the Bureau of Water Supply's policy of concentrating its pipe replacement efforts on 6-in. and smaller pipes.

28. Surprisingly, 20-in. pipes had break rates on the same order as 8-in. pipes. On closer examination, however, almost all of the breaks in 20-in. water mains were confined to a single pipe that serves the piers along Murray Hulbert Avenue. This pipe is in a fairly severe environment. This single street skewed the results for 20-in. pipes because there are only about 30 miles of 20-in. pipe in Staten Island. Otherwise, the break rate for 20-in. pipes is consistent with that of other larger pipes.

Seasonal trends

29. Seasonal trends are presented in Table 4 and Figure 3. These indicate that while break rates tend to be higher during the winter months, the increase during the winter is not as dramatic as was found in the other boroughs. The increase in winter breaks was most significant for 6-in. pipes. On the other hand, the break rate for larger pipes (>12 in.) was slightly

Table 3

Staten Island Break Rate by Type of Break and Diameter

(breaks/year/mile)

Diameter in.	Circular	Longitudinal	Blowout	Other	Unknown	Total
6	0.057	0.017	0	0.014	0.033	0.121
8-10	0.007	0.008	0.002	0.004	0.006	0.027
12	0.003	0.007	0.001	0.002	0.004	0.017
16-20	0.001	0.010	0.002	0.002	0.007	0.022
>20	0.001	0.002	0.003	0	0.001	0.007
Average	0.007	0.008	0.002	0.004	0.007	0.029

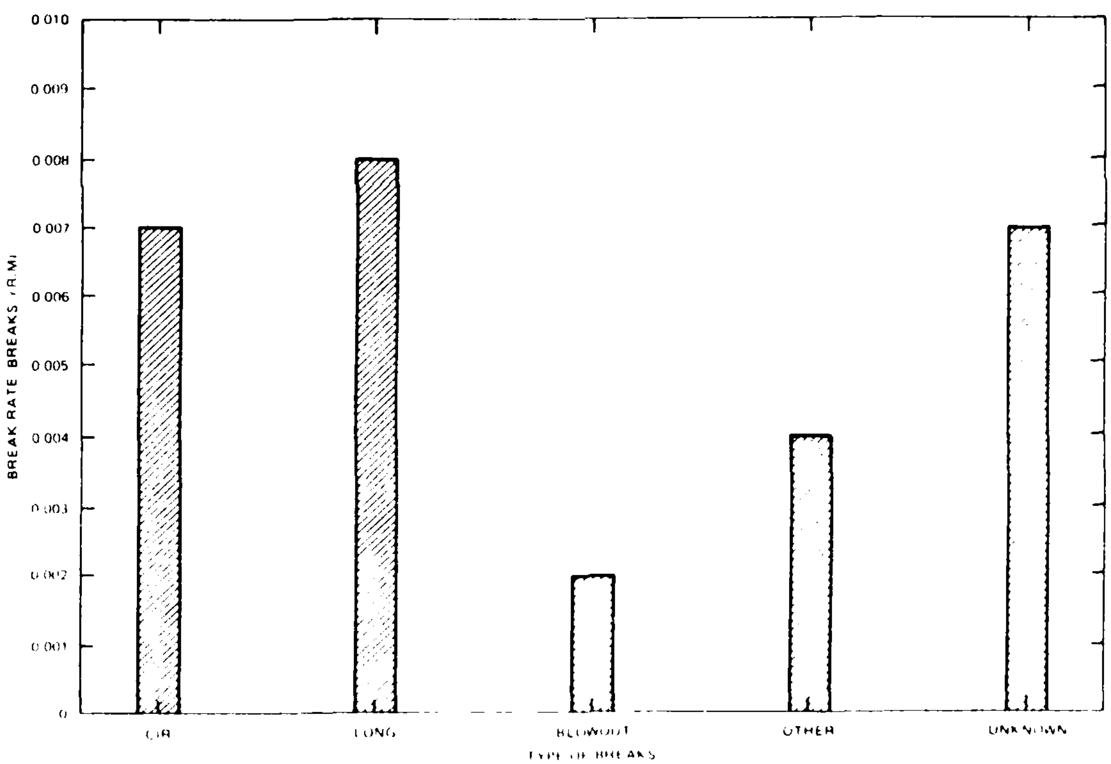

Figure 1. Break rates by type of break

greater during the summer months, indicating that frost loadings were not significant for those sizes.

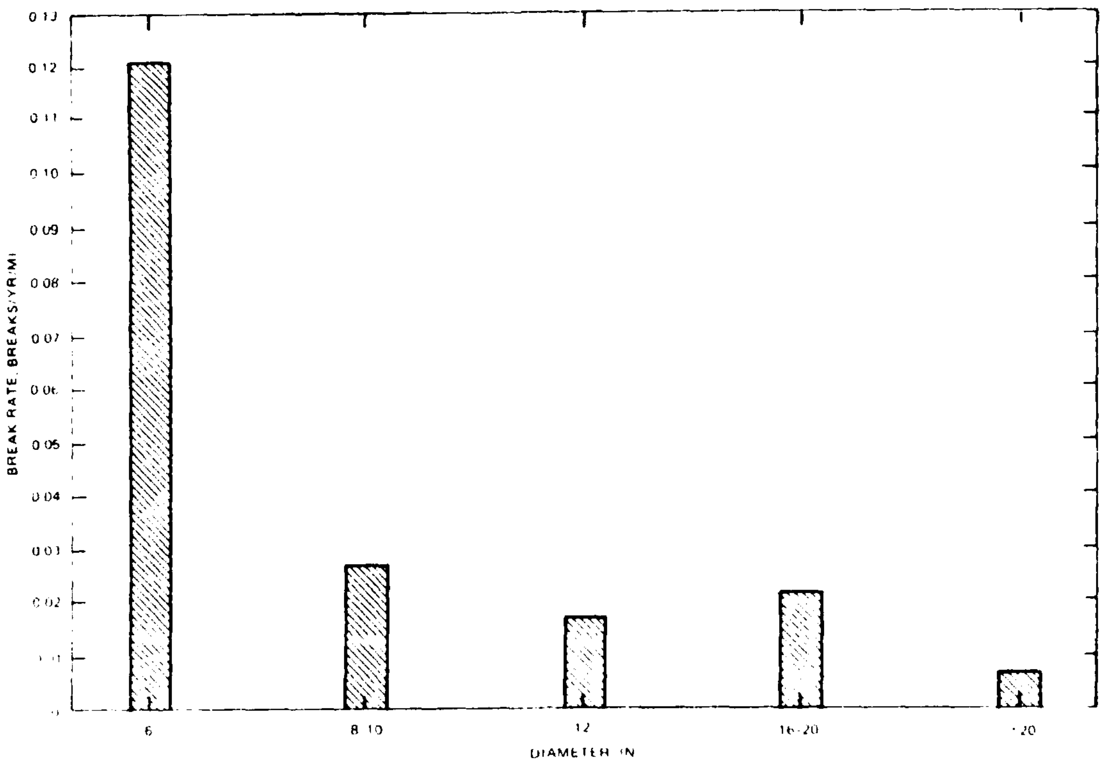

Figure 2. Break rates as a function of pipe diameter

30. Another explanation, presented above, is that waterhammer events, due to pump operation, were more common during the summer months. To test this hypothesis, break rates were calculated for pipes with either "circumferential" or "longitudinal" listed as the type of break for summer (June-September) and winter (November-February). The results shown in Figure 4 show that circumferential breaks predominated during the winter, and if longitudinal breaks occurred at the same rate as the other boroughs, the break rate would be higher during the winter. However, Staten Island is unique because of the very high number of longitudinal breaks occurring during the summer. This indicates that pump and tank operation during the summer months tends to cause surge-related breaks. This situation is further aggravated by the fact that peak demands (on a per capita basis) are much higher in Staten Island than the other boroughs. Additional investigation of pump and tank operating policies (e.g., a detailed surge analysis) in Staten Island, especially during the summer, appears to be justified.

Table 4

Staten Island Break Rate by Month and Diameter

(breaks/year/mile)

Month	Diameter: 6 in.	8-10 in.	12 in.	>12 in.	Average
Jan	0.258	0.036	0.018	0.009	0.040
Feb	0.168	0.019	0.022	0.018	0.029
Mar	0.052	0.020	0.011	0	0.020
Apr	0.206	0.017	0.022	0.018	0.027
May	0.090	0.022	0.015	0.023	0.024
Jun	0.116	0.029	0.025	0.018	0.031
Jul	0.065	0.028	0.009	0.014	0.025
Aug	0.039	0.028	0.018	0.018	0.025
Sep	0.078	0.031	0.029	0.023	0.032
Oct	0.078	0.029	0.016	0.018	0.027
Nov	0.168	0.038	0.013	0.018	0.038
Dec	0.142	0.024	0.011	0.005	0.025
Overall	0.121	0.027	0.018	0.016	0.029

Break rate versus pentad laid

31. The break rate for older water mains, as shown in Table 5 and Figure 5, is higher than that for newer mains. This is consistent with the results for other boroughs. The break rate is unusually high for pipes laid during the 1960's. This may be due to problems with quality control in pipe materials, as was observed in parts of Queens.

Break rate versus time

32. Data on the year in which a pipe were laid were incomplete for many of the pipe break records. However, the Bureau of Water Supply had records on overall pipe break rates on a borough-by-borough basis dating to 1933. These data are plotted in Figure 6. The equation that best fits these data is

$$J = 0.017 \exp [0.024(t - 1933)] \qquad (1)$$

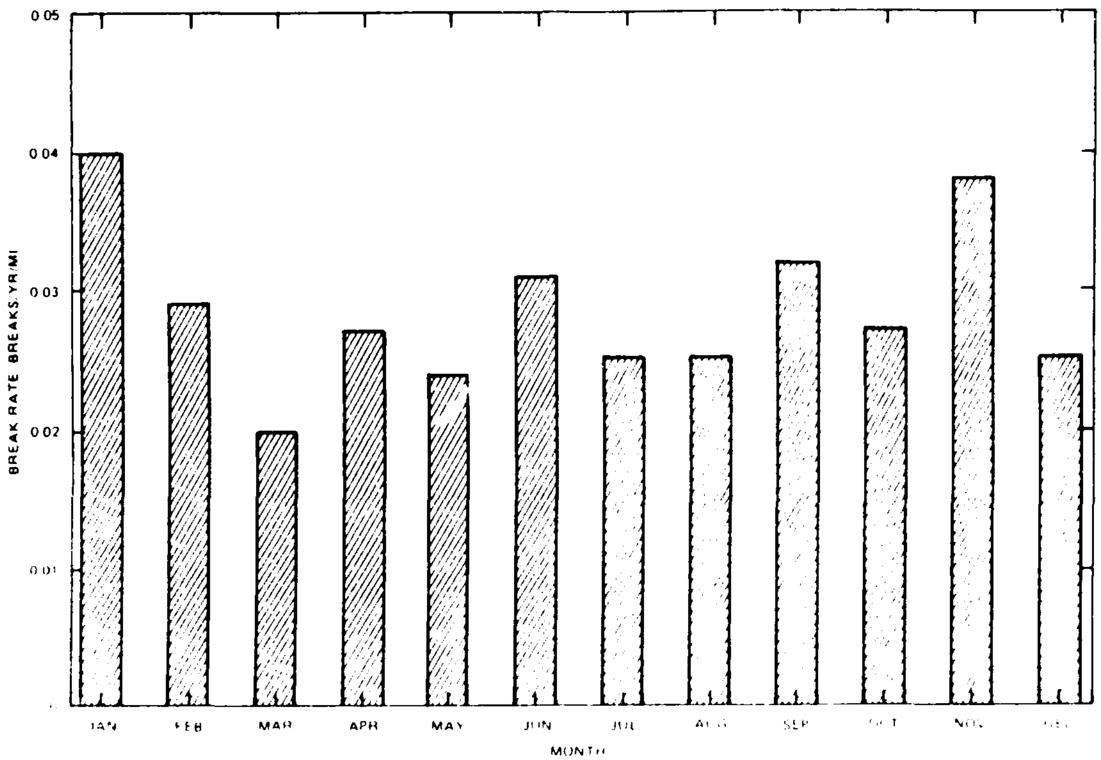

Figure 3. Break rate as a function of month

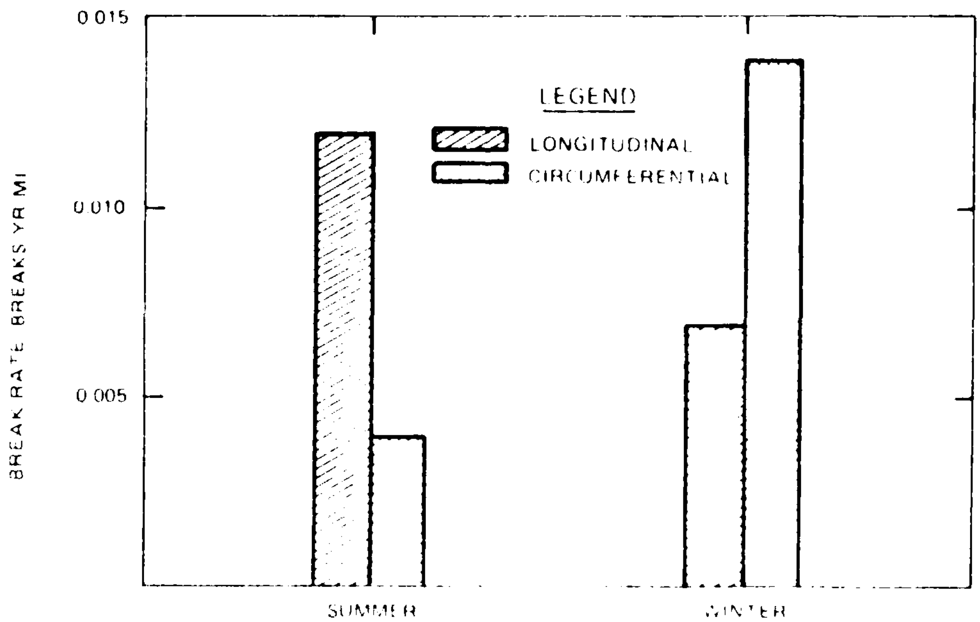

Figure 4. Seasonal trends in type of break

Table 5

Staten Island Break Rate by Pentad Laid

Pentad Laid	Break Rate (break/year/mile)
1905-09	0.050
1910-14	0.023
1915-19	0.010
1920-24	0.043
1925-29	0.039
1930-34	0.019
1935-39	0.018
1940-44	0.009
1945-49	0.006
1950-54	0.007
1955-59	0.003
1960-64	0.018
1965-69	0.013
1970-74	0.006

where

J = break rate in year t, breaks/year/mile

t = year

The curve in Figure 6 is consistent with similar curves for The Bronx and Queens, although the curves for those boroughs would fall slightly higher on the graph.

Effects of pipe deterioration due to age

33. The observation that break rates are increasing with time can be due to the fact that pipes are deteriorating with age. This hypothesis can be tested by following the pipe break record of a group of pipes (e.g., pipes laid in roughly the same time period with the same laying practices and materials) over a time span of several years (preferably several decades). This was done in Staten Island for three groups of pipes based on decade: 1910-19, 1920-29, and 1930-39.

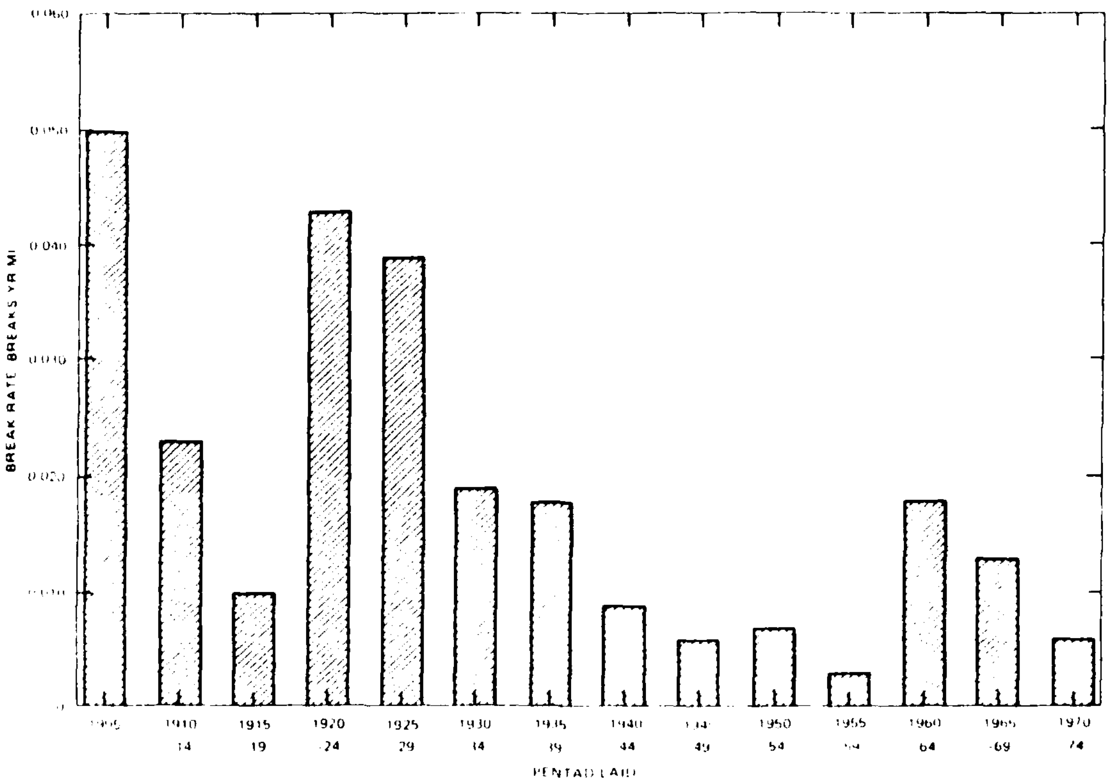

Figure 5. Break rate as a function of pentad laid

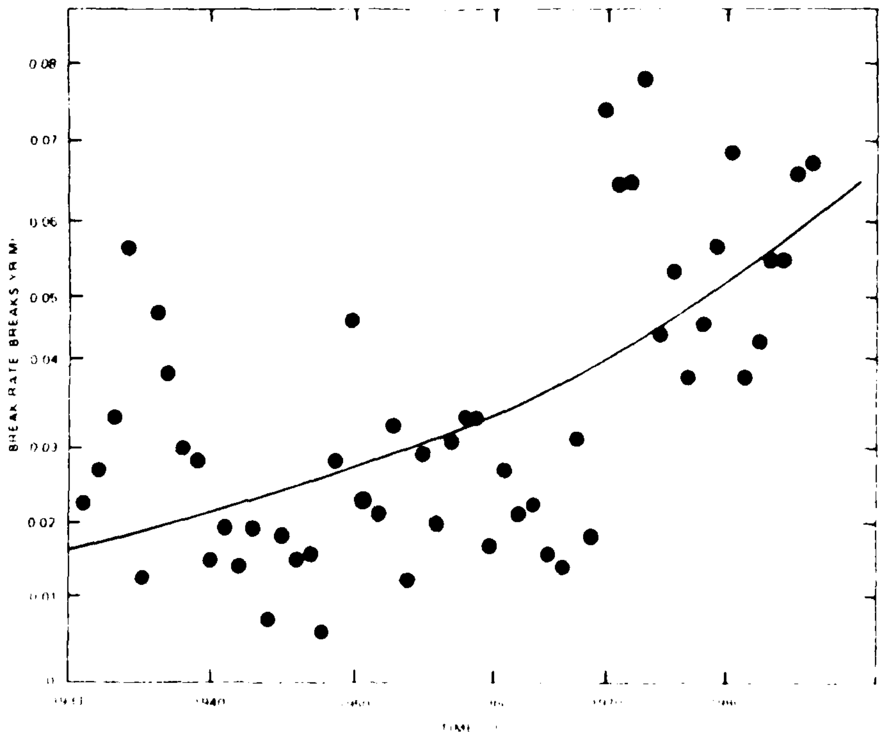

Figure 6. Break rate versus time

34. The break rate for all three groups of pipes showed the exponential growth rate observed in The Bronx and Queens. Break rates for all three groups fit Equation 2 below:

$$J = a \exp [b'(t - t_i)] \tag{2}$$

where

J = break rate, breaks/year/mile

a, b' = regression coefficients

t = year

t_i = year installed

The coefficients in Equation 2 are given below:

Decade Laid	a	b'
1910-19	0.0067	0.024
1920-29	0.0033	0.057
1930-39	0.0073	0.020

The relatively high growth rates (b') indicate that some combination of the following is occurring: (a) pipe breaks are increasing due to pipe deterioration with age, (b) pipe break data reporting is increasing with time, or (c) causes of breaks in Staten Island have become more common with time. While all three conditions may exist to some extent in Staten Island, it appears reasonable to use a value of 0.02 (i.e., 2 percent per year increase) for b' (rate of deterioration due to aging) in the economic evaluations in the Part III to estimate the increase in growth rate of breaks versus time due to deterioration. This is the value used in other boroughs.

PART III: IDENTIFICATION OF REPLACEMENT PROJECTS

35. While the statistical analyses provide some insights into the patterns and trends in water main breaks, the Bureau of Water Supply needs more specific information as to which pipes need to be replaced. This was done in this study by calculating a critical break rate, based on an economic analysis of replacement and break costs, and comparing it with the actual break rates of water mains that were candidates for replacement. If the actual break rate exceeds the critical break rate, the water main should be replaced. If the actual break rate is less than the critical break rate, it is more economical to leave the pipe in place.

Critical Break Rate

36. The formula for determining the critical break rate is based on an economic evaluation of future maintenance and repair of old mains as compared with the present worth of replacement costs. The evaluation includes water loss, leak detection, and valve maintenance. The critical break rate J^* can be given by

$$J^* = \frac{(5{,}280 r C_r - C_d) \exp(-bT) - C_w Q_o - C_v V_o}{C_b} \qquad (3)$$

where

J^* = critical break rate, breaks/year/mile

r = interest rate, fraction

C_r = cost to replace a water main, \$/ft

C_d = leak detection and repair cost, \$/year/mile

b = rate of increase of pipe breaks with time, fraction

T = number of years in the future by which pipe must be replaced

C_w = value of lost water, \$/million gallons

Q_o = leakage rate for old pipes, million gallons/year/mile

C_v = replacement cost for old valve, \$

V_o = rate of valve breakage, breaks/year/mile

C_b = cost of a main break, \$/break

The derivation of Equation 3 and guidance on how to determine values for use in that formula are presented in Appendix A to the volume on The Bronx and Queens (I lski and Wade 1987).

37. For New York City, the valve replacement cost proved to be negligible in comparison with the other cost items; therefore, it was ignored. An average value for leakage rate and leak detection cost were applied for all diameters, but the costs for replacement were a function of diameter. For calculating the critical break rate, the following values were used: $b = 0.02$, $r = 0.05$, $T = 10$ years, $C_d = \$973$/year/mile, $Q_o = 4.75$ million gallons/year/mile, $C_w = \$969$/million gallons, and $C_b = \$20,000$ per break, including only direct costs and damages. Costs of pipe replacement are given in Table 6. Additional justification for these values is given the report on The Bronx and Queens (Walski and Wade 1987).

Table 6

Unit Cost for Pipe Replacement

Diameter in.	Unit Cost $/ft
8	90
12	105
20	150
24	300
36	600
48	1,000
60	1,500
72	2,000

38. Inserting the above costs, except for replacement and break costs which depend on diameter, into Equation 3 gives:

$$J^* = \frac{(216C_r - 5,400)}{C_b} \tag{4}$$

Equation 4 was used to calculate critical break rate in Staten Island, as it was for The Bronx and Queens.

39. Break costs are especially important yet difficult to determine precisely, because all costs associated with a break should be included in the equation. However, data were available only for direct cost to the Bureau of Water Supply. Therefore, two critical break rates were determined for each diameter: the first corresponded to the case in which only direct costs were included, while the second corresponded to the case in which indirect costs were twice the direct costs. These values were selected because they bracketed the "correct" cost of a main break. The critical break rates thus determined are shown in Table 7.

Table 7

Critical Break Rates (breaks/year/mile)

Diameter, in.	No Indirect Cost	High Indirect Cost
8	1.23	0.27
12	1.17	0.31
20	1.61	0.47
36	5.49	1.98
48	9.31	3.36
60	14.1	5.09

40. The replacement criteria based on critical break rates should not be regarded as an absolute rule for pipe replacement but as an indicator of which mains should be replaced. This is because the potential for damages from a break and the actual leakage rates and replacement cost will vary widely throughout the system. The critical break rates shown in Table 7 are based on average values as a function of diameter only.

Determining Actual Break Rates

41. Next it was necessary to calculate the actual break rate of individual pipe segments. If each break in the break file could be related to a pipe

segment in the inventory file, this would be a simple automated procedure. However, since this was not possible, nor was it possible to prepare a computerized map of breaks, it was necessary to manually locate breaks and calculate actual break rates.

42. This process was a two-step procedure. First, each break was plotted on large-scale street maps of the city. Different color codes were used for areas with one, two, or more breaks. This exercise, which involved manually locating approximately 600 pipe breaks in Staten Island, was used to identify the pipes that were possible candidates for replacement. In this way, it was necessary to calculate the actual break rate for only a relatively small number of pipes. Next, the Bureau of Water Supply's distribution maps were used to pinpoint the pipe segment that broke (there could be several pipes in a street), count the number of breaks, and measure the length of the pipe project under consideration. From this information the actual break rate for a candidate replacement project could be calculated as

$$J = \frac{5,280N}{(1980 - Y)L} \tag{5}$$

where

J = actual break rate, breaks/year/mile

N = number of breaks

Y = year of first break

L = length of system over which breaks occurred, ft

(The year 1980 represents the last year for which break data were included in the data file used.)

43. Note that the actual break rates were calculated for "replacement projects" rather than individual "pipe segments." A replacement project consisted of several contiguous pipes segments. This was done because of: (a) problems in precisely locating some breaks and (b) economies of scale which exist in pipe replacement. The unit cost of pipe replacement for several contiguous blocks is somewhat less than that for a single block because mobilization costs can be spread over a larger project. When a break could only be located to an intersection, one-half the length of each of the four blocks connected to the intersection was used to calculate L .

44. The length of time between the first break and 1980, the last year covered by the break data file, was used in calculating break rates for this study. This differs from the procedure used for The Bronx and Queens, in which the total time covered by the break file, 25 years, was used. Using the total period of break records would be inaccurate in Staten Island because so many pipe records were missing from the break data file.

45. The result is that the calculated actual break rates are higher for Staten Island than for The Bronx and Queens and, therefore, more projects have been identified for replacement. However, some caution needs to be exercised in using these values. For example, Forest Avenue between Jewett Avenue and Llewellyn Place broke twice in the 1971-80 time period. It therefore has a very high break rate (4.89 breaks/year/mile) and should be replaced if that break rate continued. If, however, the pipe has not broken since 1980, its break rate should be recalculated using "present-1971" as the time period over which the breaks occurred. This will reduce the actual break rate and may eliminate some of the projects with only two or three breaks from the list of [illegible] projects. Pipes with one break are not included in Table 8 because a single break could be an anomaly.

[illegible]. The actual break rates were compared with critical break rates to identify economically justifiable replacement projects. These projects were [illegible] into two categories depending on which of the two critical break rates [illegible] was exceeded.

[illegible]. Pipe segments with high break rates are listed in Table 8. Most of the [illegible] identified were laid in the 1920's. However, three potential projects [illegible] modern pipes laid during the early 1960's. These include Ridge Avenue between Vista and Sparkhill Avenues, Clairmont Avenue between Vogel Avenue and [illegible], and North Gannon Avenue near Crafton Avenue. The North Gannon [illegible] located near the Staten Island Expressway and may endure heavy loads [illegible] traffic. However, the other mains are in less congested areas [illegible] tend to indicate poor quality pipe.

Replacement of Small Pipes

[illegible]. Water mains with diameters smaller than 8 in. tend to have higher [illegible] than larger diameter mains due to the smaller pipes' reduced [illegible] to withstand beam loadings. For this reason (and for increased

Table 8

Pipes Requiring Replacement, Staten Island

Pipe Location	Year First Break	Breaks	Diam in.	Length ft	Break Rate*
	I. Pipes Needing Replacement (High Indirect Cost)				
Van Pelt Ave near intersection of Huesdon and Linden Sts	1977	2	8	600	5.87
Forest Ave between Jewett Ave and Llewellyn Place	1971	2	12	240	4.89
Beechwood Ave between Crescent Ave and Cleveland Place	1972	2	8	320	4.12
Van Duzer St near St Paul Ave	1971	3	8	440	4.00
Kissam Ave between Old Mill Rd and Cedar Grove Ave	1951	38	8	1800	3.84
Jersey St near Richmond Terrace	1973	2	8	400	3.77
Richmond Terrace at Bard Ave	1964	2	10	240	2.75
Broadway between Coughlan Ave and Tyler Ct	1971	2	12	440	2.67
Colon Ave between Arthur Kill and E. Gurley Ave	1973	2	8	640	2.36
Bay St near Vanderbilt Ave	1960	6	8	680	2.32
Beach Ave near Railroad Ave	1955	2	8	320	2.20
Poplar Ave at Rossville Ave	1972	2	8	640	2.06
Ridgewood Ave between Barlow Ave and Leverett Ave	1973	3	8	1200	1.89
Davis Ave between Davis Ct and Walnut St	1973	2	8	880	1.71

(Continued)

* Breaks/year/mile.

(Sheet 1 of 3)

Table 8 (Continued)

Pipe Location	Year First Break	Breaks	Diam in.	Length ft	Break Rate*
I. Pipes Needing Replacement (Cont.)					
Ridge Ave between Vista Ave and Sparkhill Ave	1968	4	8	1040	1.69
Clairmont Ave between Vogel Ave and Amboy Rd	1965	2	12	440	1.60
Treadwell Ave between Hatfield Ave and Charles Ave	1961	3	8	580	1.43
Vanderbilt Ave near Murray Hulbert Ave	1969	2	8	720	1.33
II. Pipes Probably Needing Replacement (Low Indirect Cost)					
Murray Hulbert Ave along Piers	1951	25	20	3000	1.52
Rector St between Hurst St and Post Ave	1950	2	8	440	1.20
Vedder Ave between West Shore and Willowbrook Rd; College Ave between Willowbrook Rd and Crystal Ave; Pontiac St between Riegelmann Ave and Forest Ave; Forest Ave between Willowbrook Rd and Arnprior St	1963	5	8-12	3200	1.18
Laconia Ave between Buel Ave and Liberty Ave; Seaver Ave between Hylan Blvd and Laconia Ave; Seaver Ave at Mason St	1964	7	8	1960	1.18
Seaver Ave between Peterson Ave and Father Capadana Blvd; Graham Blvd between Freeborn Ave and Jay St; Patterson Ave between Jefferson Ave and Graham Blvd	1943	18	8	2200	1.16
Near intersection of Lawrence Ave and Parkview Place	1961	2	8	480	1.16

(Continued)

(Sheet 2 of 3)

Table 8 (Concluded)

Pipe Location	Year First Break	Breaks	Diam in.	Length ft	Break Rate*
II. Pipes Probably Needing Replacement (Cont.)					
Olympia Blvd between Jefferson Ave and Graham Blvd; E. Hunter Ave between Olympia Blvd and Grimsby St; Grimsby St between Mildred Ave and Jefferson Ave; Mapleton Ave between Grimsby St and Freeborn Ave	1951	20	8	3260	1.12
Arthur Kill Rd at Muldoon St	1966	2	12	800	0.94
Villa Ave near intersection with Walker St; LaForge Place between Burden Ave and Hooker Place	1943	4	8	680	0.84
Wooley Ave between Purdy Ave and Westward Ave; N. Gannon Ave between Ardmore Ave and Warwick Ave; Crafton Ave near Staten Island Expressway	1969	3	8-12	3240	0.82
Old Mill Rd between Tarlton St and Fox Lane; Tarlton St between Old Mill Rd and Cedar Grove Ave; Fox Lane between Old Mill Rd and Rochelle Ave	1944	18	8	3400	0.78
Cuba Ave between Isernia Ave and Ebbits St; intersection of Ebbits St and Hett Ave	1948	4	8	1200	0.55
Davis Ave between Delafield Ave and Castleton Ave	1952	3	8	1040	0.54
Bay St between Greenfield Ave and St Mary's Ave	1946	5	8	1600	0.48

(Sheet 3 of 3)

hydraulic capacity), the Bureau of Water Supply has been replacing 6-in.-diam and smaller water mains with larger mains. Therefore, an evaluation of actual versus critical break rates is not necessary for these sizes of pipes.

49. In an effort to determine priorities for small pipe replacement, Table 9 was prepared to identify those small water mains that have had more than one break. These should be regarded as the first pipes to be replaced. Table 9 also shows that the data on "year laid" are especially poor for small pipes, probably because most of the smaller pipe was laid by private companies.

Budget Estimates for Repair and Replacement

50. Without a significant pipe replacement program, break rates in Staten Island are likely to continue to increase, as predicted in Equation 1. Using $8,600 as the average direct cost to the Bureau of Water Supply for a pipe break, and 786 as the current total number of miles of water mains, it is possible to project the water main repair cost for the Bureau into the future. These projected costs are presented in Table 10. They do not account for indirect costs, inflation, or the fact that the Staten Island system will probably grow in the future. Therefore, the values represent a lower bound for repair costs (in the absence of a replacement program).

51. Water main breaks in Staten Island currently occur at the rate of about one per week. However, if a replacement program is not initiated, the rate will likely increase to one break every third day by the early 2000's. Since 1 percent of the system accounts for approximately 37 percent of the breaks, replacing that small percentage can significantly reduce expenditures for repair.

52. To budget the recommended replacement projects, cost estimates were made for each project shown in Table 8. Costs were taken from Table 6. Projects were categorized by size and need for replacement. The resulting costs and lengths of pipe needing replacement are shown in Table 11.

53. The replacement costs given in Table 11 are only approximations. The lengths of some projects may be different because of problems in isolating portions of the system; some water mains may already have been replaced; or some candidate projects may no longer be experiencing problems.

Table 9

Small Pipes with Multiple Breaks, Staten Island

Location	Number of Breaks	Diameter	Year Laid
Purdy Place between Van Wyck Ave and Seguine Ave	6	6	1921
Faber St near Richmond Terrace	5	6	--
Murray Hulbert Ave near Piers	4	6	1921
Gordon St near Laurel Ave	3	6	--
Clove Rd near Targee St	3	6	--
Bay St between Hannah St and St Julian Place	3	4-6	--
Bay St at Clifton Ave	2	6	--
McClean Ave near Sand La	2	6	--
Richmond Ave at Richmond Terrace	2	6	--
2000 block of Richmond Terrace	2	6	--
Richmond Terrace at Wall St	2	6	--
91 Grimsby Place	2	6	1923
Park Ave at Richmond Terrace	2	6	--
Canal St at Wright St	2	6	--
Hooker Place at Tranton Place	2	4	--
84 Linwood Ave	2	4	--

Table 10

Projection of Number of Breaks and Direct Repair Costs

Staten Island

Year	Number of Breaks	Annual Repair Cost (K$)
1985	46	400
1990	53	451
1995	59	509
2000	67	574
2010	85	729
2020	108	927
2040	174	1,500

Table 11

Replacement Cost Estimates, Staten Island

	Category I Needing Replacement		Category II Possible Replacement		Total	
Diameter in.	Length miles	Cost (K$)	Length miles	Cost (K$)	Length miles	Cost (K$)
8	1.94	923	3.69	1,752	5.63	2,675
12	0.26	143	0.76	422	1.02	565
20	0	0	0.57	450	0.57	450
Total	2.20	1,066	5.02	2,624	7.22	3,690

54. If the replacement costs are spread over 10 years, the annual cost will be approximately $300,000 per year. If such projects will reduce pipe breaks by one third, the savings (if one includes indirect costs and damages) will more than pay for the projects.

Other Rehabilitation Considerations

55. The above replacement analysis is based on the assumption that the water mains will be replaced by mains of the same diameter. Some hydraulic analysis should be conducted, however, to ensure that such diameters will be adequate. In some cases, increased water use may necessitate larger mains.

56. Older pipes that were not marked for replacement can reasonably be considered to be structurally sound. Therefore, if they have lost internal carrying capacity, they may be candidates for pipe cleaning and lining projects. This is especially true for larger pipes for which cleaning and lining are especially attractive (Walski 1984).

PART IV: SUMMARY AND CONCLUSIONS

57. Water mains in Staten Island are deteriorating much like those in any other large city. While Staten Island is somewhat less developed than the other boroughs of New York City, its water mains have many of the same problems, plus a few that are unique.

58. Water mains in Staten Island are breaking at a rate slightly lower than that in The Bronx, Brooklyn, and Queens and much lower than in Manhattan. The overall break rate between 1940 and 1980 is 0.029 break/year/mile. As is the case with the other boroughs, the rate is increasing about 2 percent per year.

59. Smaller pipes in Staten Island tend to suffer primarily from circumferential breaks, and these occur most frequently during winter months. However, the break rate in Staten Island does not decrease during the summer as it does in the other boroughs. Instead, the number of longitudinal breaks, most likely triggered by surges, increases during the summer.

60. As was the case with the other boroughs, 6-in. pipes had the highest break rates. Small pipes with multiple breaks are identified in Table 9.

61. Water mains laid before 1910 and during the 1920's had the highest break rates. However, break rates for some pipes laid in the 1960's were higher than expected. This may be attributable to some bad batches of pipe, as was found in Queens.

62. One percent of the water mains accounted for 37 percent of the pipe breaks. Identifying and replacing these pipes could result in lower maintenance costs for the borough.

63. In areas of the distribution system with a high number of breaks, the break rates were calculated for water mains involved in potential pipe replacement projects. These actual break rates were compared with a critical break rate to determine if it was economically justifiable to implement these replacement projects. The critical break rate was determined by a comparison of the cost of replacement with the cost for maintenance and repair of the existing water main.

64. Because of uncertainty in determining the indirect cost of a pipe break, a range of critical pipe breaks was determined, one with negligible indirect costs, another with indirect costs twice that of direct costs.

65. Approximately 7 miles of replacement projects were identified at an estimated cost of $3.6 million.

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